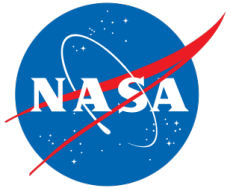
Preparing to Use Satellite Data

TCEQ Training Course
February 24 – 27, 2014

ARSET

Applied Remote SEnsing Training

A project of NASA Applied Sciences



Short

A Dictionary of Aerosol Remote Sensing Terms

Part 1

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Let’s look at 3 kinds of properties that are important to understand about aerosols

Physical Properties

Optical Properties

These two types of properties are very closely linked in remote sensing because we infer the Physical properties from Optical measurements

Chemical Properties

Physical Properties

Aerosol Amount

- AOD - Aerosol Optical Depth
- AOT - Aerosol Optical Thickness

These optical measurements of light extinction are used to represent aerosol amount in the entire column of the atmosphere.

Multiple Conditions Can Result in the Same AOD

Heavy AOD
Below the planetary boundary layer

Moderate AOD ~0.40
Near Mt. Abu, India

Photos courtesy of Brent Holben

AOD and PM2.5

AOD is a unitless quantity

Sample AOD values:

0.02 - very clean isolated areas

0.2 – fairly clean urban area

0.4 – somewhat polluted urban area

0.6 – fairly polluted area

1.5 – heavy biomass burning or dust event

Equivalent PM2.5 mass concentration

~ 1 μm^{-3}

~ 12 μm^{-3}

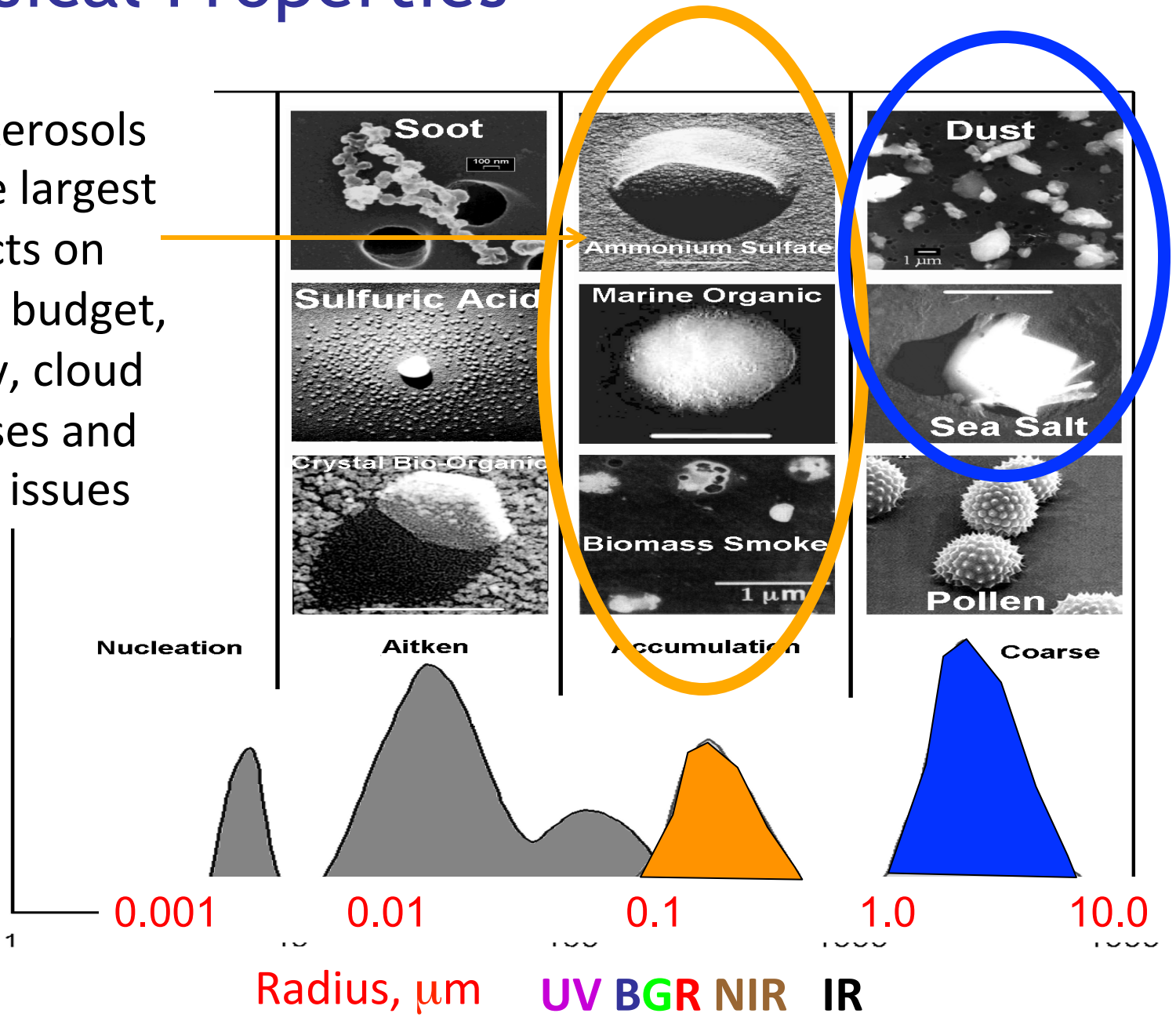
~ 24 μm^{-3}

~ 36 μm^{-3}

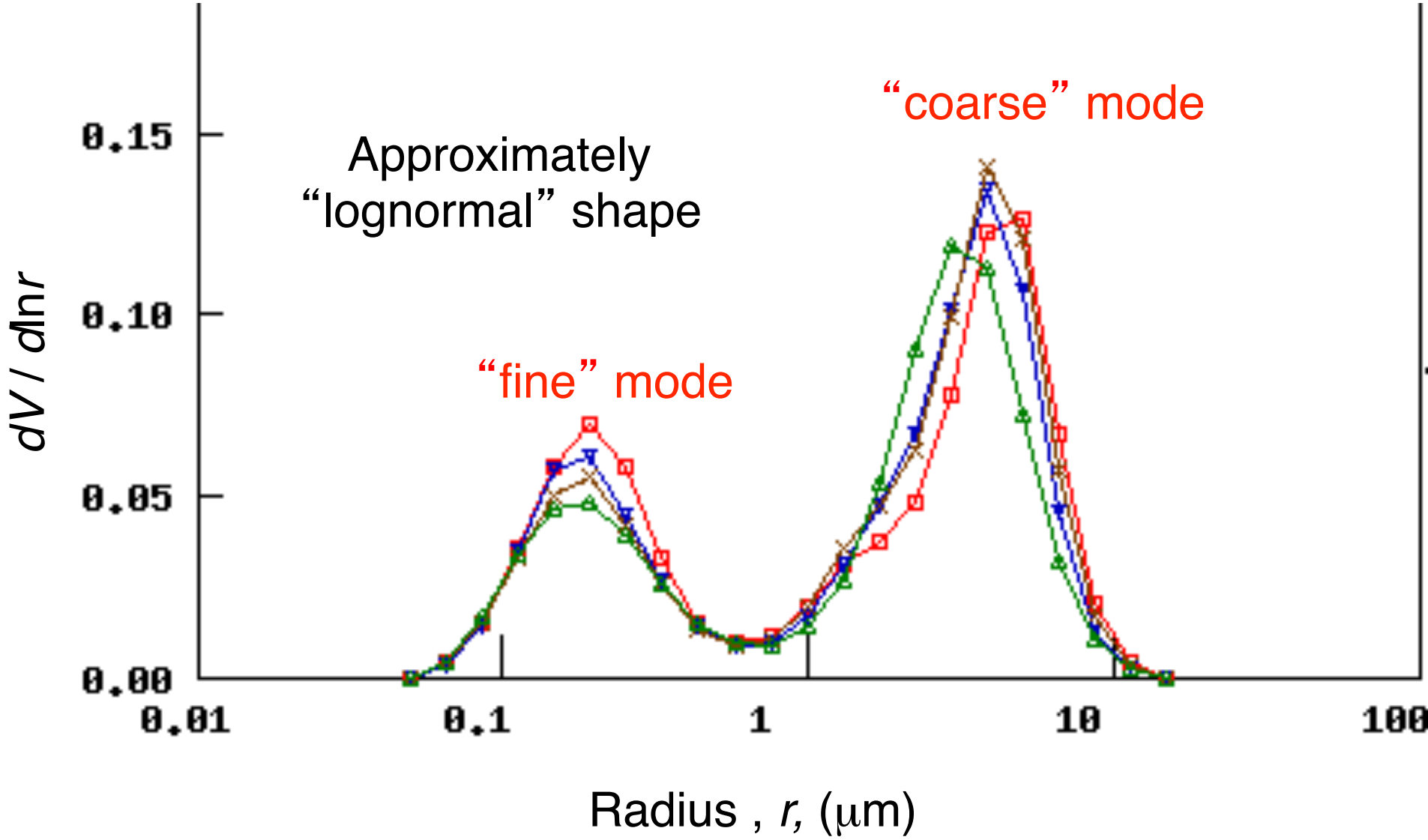
~ 90 μm^{-3}

Physical Properties

These Aerosols have the largest impacts on radiative budget, visibility, cloud processes and health issues



Size Distribution



Physical Properties –
Particle Size and Size Distribution

Fine Mode - The mode representing the small aerosol has a size distribution centered on radii between 0.1 and 0.25 microns.

Coarse Mode - The mode representing the large aerosol has a size distribution centered on radii between 1 and 2.5 microns.

Why is Size Distribution Important?

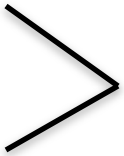
It can be an indicator of the aerosol source.

MAN MADE – A result of a combustion process

Smoke

(Biomass Burning)

Industrial Pollution



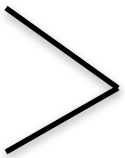
Small

(Fine Mode)

NATURAL – A result of a wind or erosion process

Sea Salt

Dust



Large

(Coarse Mode)

Physical Properties

Fine Fraction
A simple ratio of the volume of fine particles to the total volume of particles.

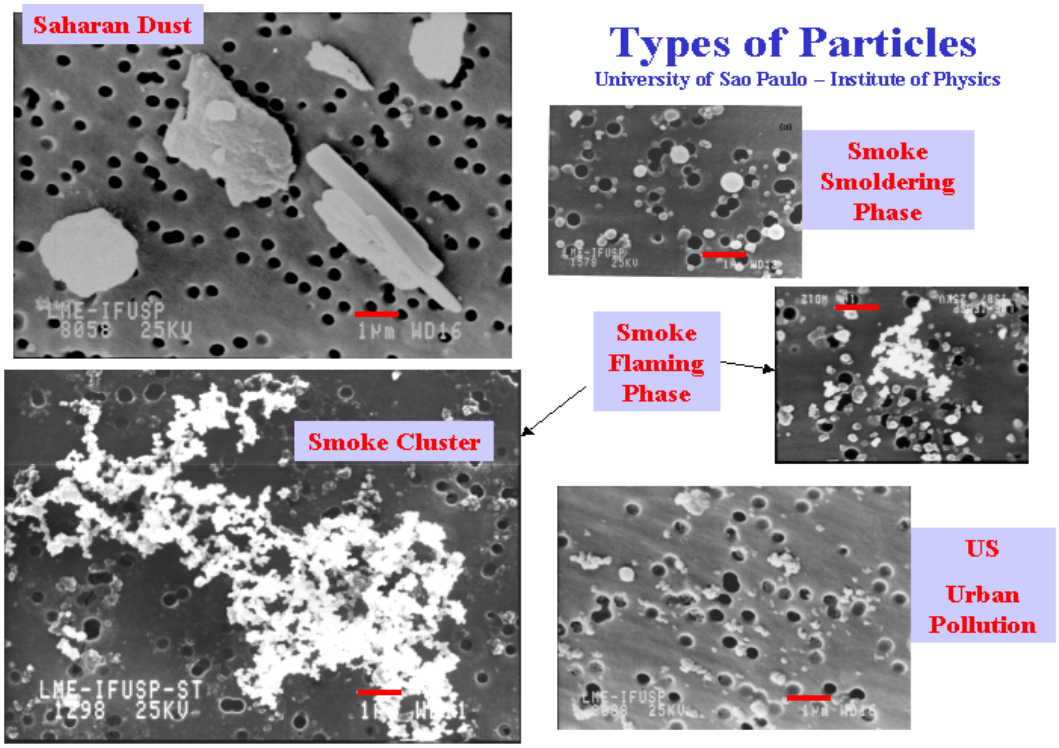
Values range from 0 - 1

Fine AOD
The fraction of light extinction due to particles in the fine mode.

Total AOD x Fine Fraction

Physical Properties

Particle shapes – **spherical, spheroid, non-spherical**



Particle shape can:

- be indicative of the source and age of the particle
- influence climate processes
- affect how active aerosols are in the lungs

Optical Properties

Optical properties are important for several reasons

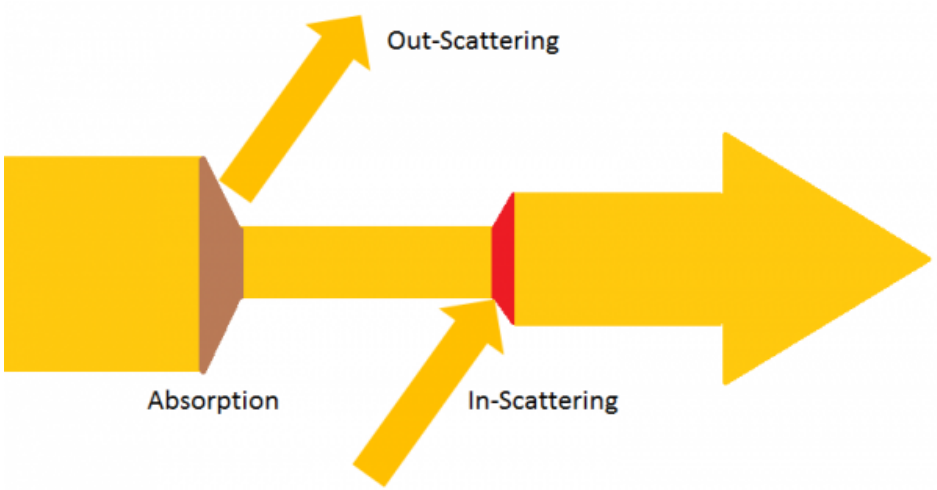
1) Their effect on the radiative balance of the Earth's environment

2) Their effect on heating of the atmospheric column which can change circulation and affect the water cycle

3) Visibility

Optical Properties

Extinction = Scattering + Absorption



Light Scattering
Light Absorption
$>$
These quantities are difficult
to separate and measure individually

Optical Properties

Single Scattering Albedo - a measure of how absorbing or scattering we consider the mass of aerosol particles.

$$\omega_o = \frac{AOT_{scatter}}{AOT_{scatter} + AOT_{absorption}}$$

Values of .85 are considered moderately absorbing
Values of .95 are considered non-absorbing

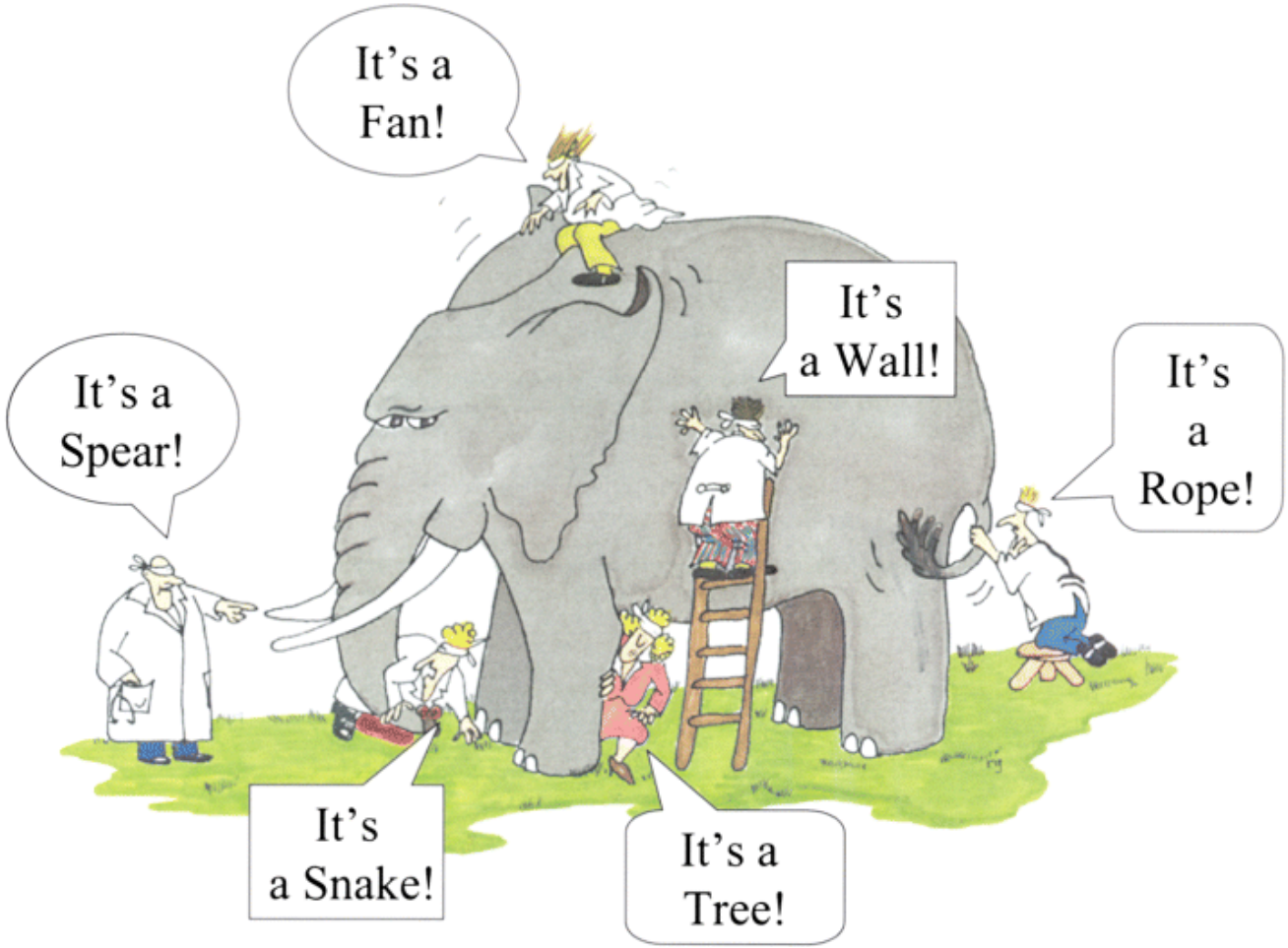
Significance for Air Quality: Can be an indicator of chemical composition and/or source

Radiative Transfer

The physics and mathematics of how radiation passes through a medium that may contain any combination of scatterers, absorbers, and emitters.

Aerosol Inversion

Since we cannot directly physically measure the aerosols we must infer their properties from optical measurements.



Aerosol Inversion

Using the measured optical properties to infer the physical characteristics of the Aerosol.

This is performed by an inversion of the Radiative Transfer Equations.

Aerosol Inversion

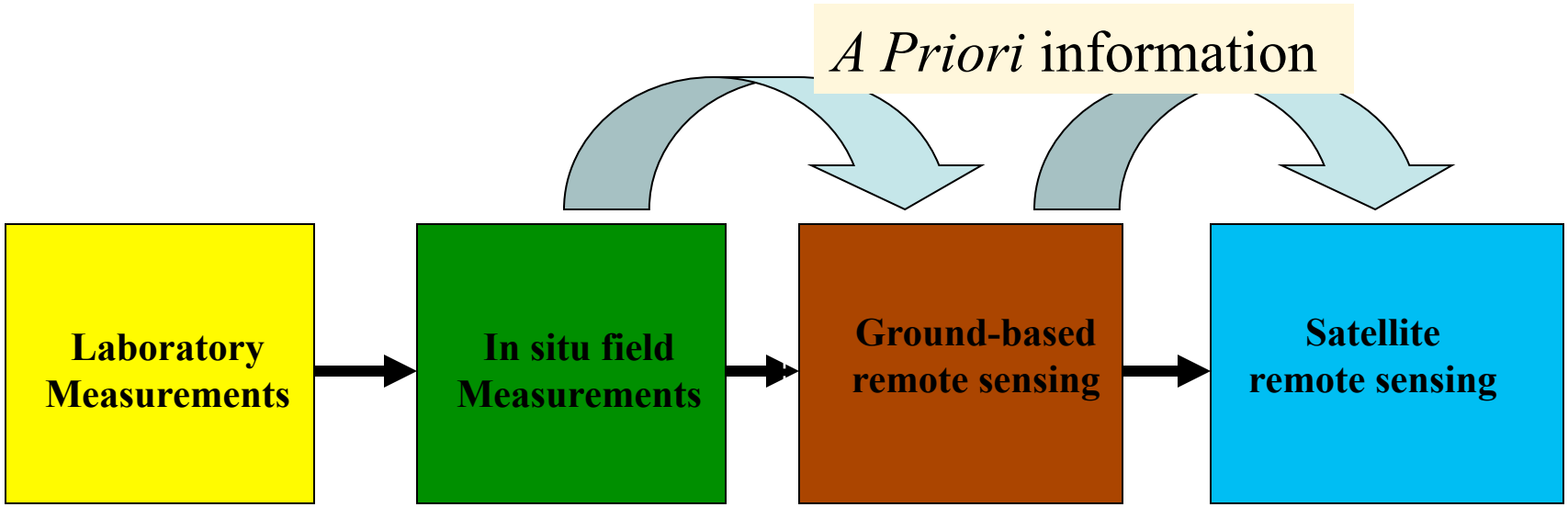
Usually we start with the object and obtain the measured properties.

An inversion works backwards.
We start with a set of measured optical properties.
We work backwards mathematically to determine which set of aerosols fit the optical properties.

There are many possible physical conditions that can produce the measured set of observations.

We use several assumptions to come to the correct conclusions – NOT Guesswork

Linkages



Chemical prop
- Optical prop
- Particle shape

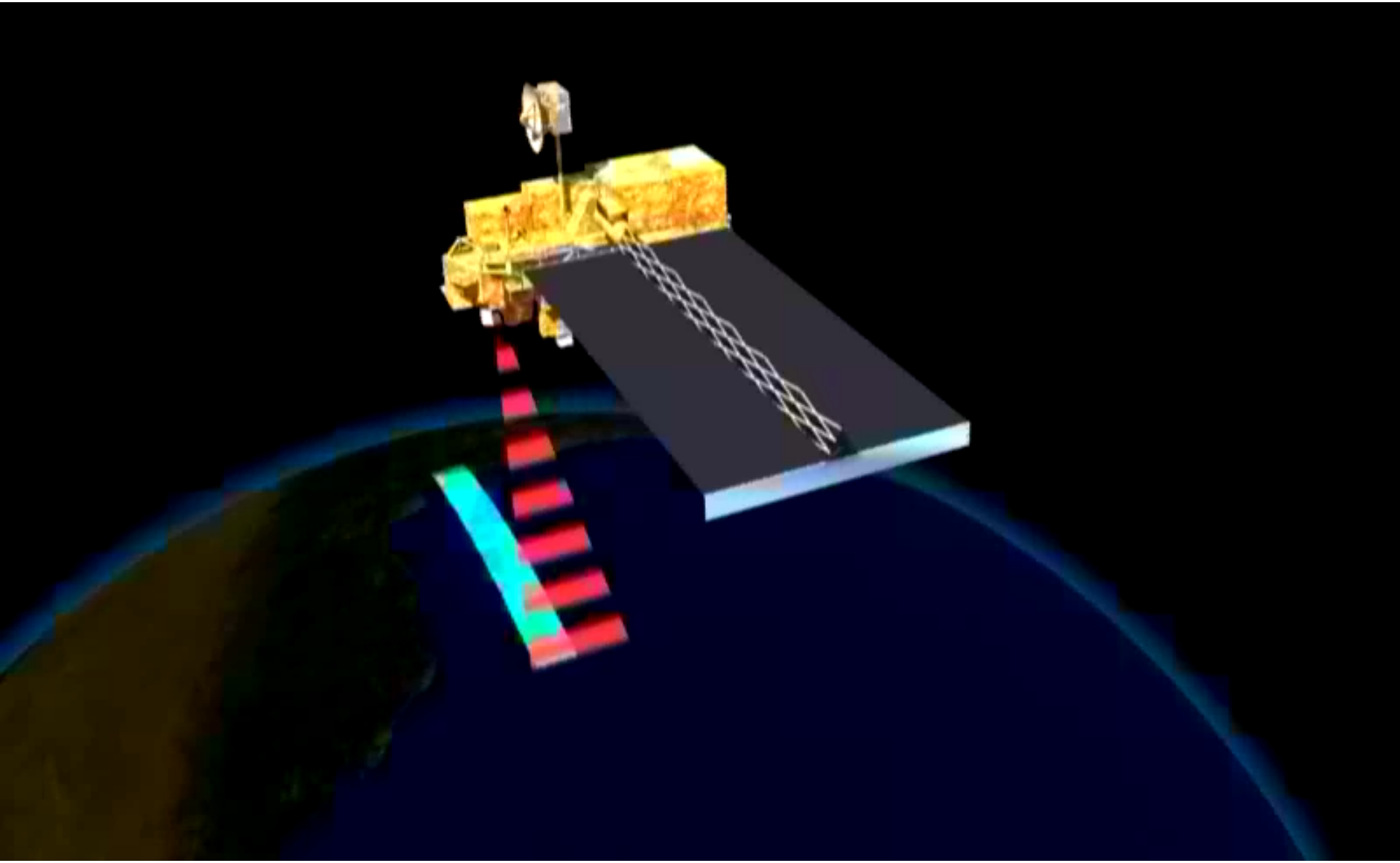
Aethalometer
- Nephalometer
- Particle Counters
- TEOM

Direct-sun
- Sky-radiance
- Hem. Irradiance
- Lidar

Solar occultation
- Solar backscattered
- Lidar

MODIS and Satellite Data Organization

MODIS Scan Pattern



MODIS Reflected Solar Bands

250 M

500 M

Primary Use	Band No.	Bandwidth (nm)	Spectral Radiance	Required SNR
Land/Cloud Boundaries	1**	620-670	21.8	128
	2**	841-876	24.7	201
Land/Cloud Properties	3*	459-479	35.3	243
	4*	545-565	29.0	228
	5*	1230-1250	5.4	74
	6*	1628-1652	7.3	275
	7*	2105-2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405-420	44.9	880
	9	438-448	41.9	838
	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516
Atmospheric Water Vapor	17	890-920	10.0	167
	18	931-941	3.6	57
	19	915-965	15.0	250

* 500m Spatial Resolution
** 250m Spatial Resolution

Spectral Radiance values are in W/m^2-um-sr
SNR = Signal-to-noise ratio

MODIS Thermal Bands

Primary Use	Band	Bandwidth (μm)	Spectral Radiance	Required NEDT (K)
Surface/Cloud Temperature	20	3.660-3.840	0.45(300K)	0.05
	21	3.929-3.989	2.38(335K)	2.00
	22	3.929-3.989	0.67(300K)	0.07
	23	4.020-4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433-4.498	0.17(250K)	0.25
	25	4.482-4.549	0.59(275K)	0.25
Cirrus Clouds	26	1.360-1.390	6.00	150 (SNR)
Water Vapor	27	6.535-6.895	1.16(240K)	0.25
	28	7.175-7.475	2.18(250K)	0.25
	29	8.400-8.700	9.58(300K)	0.05
Ozone	30	9.580-9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780-11.280	9.55(300K)	0.05
	32	11.770-12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185-13.485	4.52(260K)	0.25
	34	13.485-13.785	3.76(250K)	0.25
	35	13.785-14.085	3.11(240K)	0.25
	36	14.085-14.385	2.08(220K)	0.35

Spectral Radiance values are in W/m^2-um-sr
NEDT = Noise-equivalent temperature difference

MODIS Products

(MOD for Terra/MYD for Aqua)

MOD01 Level-1A Radiance Counts
MOD02 Level-1B Calibrated Geolocated Radiances
-also Level 1B "subsampled" 5kmX5km pro
MOD03 Geolocation Data Set
MOD04 Aerosol Product
MOD05 Total Precipitable Water
MOD06 Cloud Products
MOD07 Atmospheric Profiles
MOD08 Gridded Atmospheric Product (Level 3)
MOD09 Atmospherically-corrected Surface Reflectance
MOD10 Snow Cover
MOD11 Land Surface Temperature & Emissivity
MOD12 Land Cover/Land Cover Change
MOD13 Vegetation Indices
MOD14 Thermal Anomalies, Fires & Biomass Burning
MOD15 Leaf Area Index & FPAR
MOD16 Surface Resistance & Evapotranspiration
MOD17 Vegetation Production, Net Primary Productivity
MOD18 *Normalized Water-leaving Radiance
MOD19 Pigment Concentration
MOD20 Chlorophyll Fluorescence
MOD21 *Chlorophyll_a Pigment Concentration
MOD22 Photosynthetically Active Radiation (PAR)
MOD23 Suspended-Solids Conc, Ocean Water
MOD24 Organic Matter Concentration
MOD25 Coccolith Concentration
MOD26 *Ocean Water Attenuation Coefficient
MOD27 Ocean Primary Productivity
MOD28 *Sea Surface Temperature
MOD29 Sea Ice Cover
MOD32 Processing Framework & Match-up Database
MOD33 Gridded Snow Cover
MOD34 Gridded Vegetation Indices
MOD35 Cloud Mask
MOD36 Total Absorption Coefficient
*MOD37 Ocean Aerosol Optical Thickness
MOD39 Clear Water Epsilon
MOD43 Albedo 16-day L3
MOD44 Vegetation Cover Conversion

Data Product Hierarchy

This structure is common to many satellite products

Level 1 Products – Raw data with and without applied calibration.

Level 2 Products – Geophysical Products (sometimes gridded)

Level 3 Products – Globally gridded geophysical products

Data Product Hierarchy and Description

	Product Category	File Name Examples	Product Contains
Level 1	**Raw data**	**MOD02 MYD02**	**Radiance values from all sensor channels**
Level 2	**Geophysical Product from a single overpass**	**MOD04 MYD04**	**All parameters for a single product - Aerosol product**
Level 3	**Global Gridded product from multiple overpasses**	**MOD08 MYD08**	**Selected parameters for all atmospheric products -Aerosol, Cloud, Water Vapor, Atmospheric Profile**

Level 1 Products - Often referred to as Level 1B

MOD02 = Level 1B

File Type Name:

MOD02 - Raw (calibrated) data containing all of the individual channels.

File Used For:

Constructing Images

Creating Geophysical Products

Level 1 Products - MOD02 = Level 1B

MOD021KM – 1KM calibrated geo-located radiances

MOD02HKM – .5 KM calibrated geo-located radiances

Bands	Nm	Name
3	459-479	.47
4	545-565	.55
5	1230-1250	1.2
6	1628-1652	1.6
7	2105-2155	2.1

MOD02QKM – .25 KM calibrated geo-located radiances

Bands	Nm	Name
1	620-660	.66
2	841-876	.87

Organization of the MODIS DATA

MOD - Terra product

MYD - Aqua product

Granule - A 5 minute piece of a MODIS orbit

Level 1 Products (granule)

MOD02 Level 1B Calibrated geo-located radiances

MOD03 1Km Geolocation Fields

MODIS Product Hierarchy

Level 1 Products

Radiance - 250m, 500m, 1km

Level 2 Products

Aerosol – 10km

Level 3 Products

Aerosol – 1 deg Daily/8day/Monthly

More User Control

Less User Control

Harder to Use

Easier to Use

Satellite Product Usage

Level 2 Products

Aerosol – 10, 3, 1 km

- Highest resolution products
- Requires expertise to extract and use the values
- This level of product is integrated into some products and tools.
- Applications exist to visualize the data with moderate level of knowledge

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Level 3 Products

Aerosol – 1 deg
Daily/8day/Monthly

- Lower resolution products
- This level of product is integrated into many products and tools.
- Available tools may have limited ability to select and filter data

MODIS LEVEL II PRODUCTS

Geophysical parameters derived from MODIS radiances

MOD04 **Aerosol**

MOD06 **Cloud**

MOD05 **Water Vapor**

MOD07 **Atmosphere Profile**

MOD35 **Cloud Mask**

A few important terms for level 2 and 3 derived products

Collection refers to a coherent grouping of the data.
A collection is usually processed by the same set of algorithms

Aqua (MYD) and Terra (MOD) products are currently collection 5
Collection 6 is scheduled to be released very soon.

Changes in the calibration of the instrument may coincide with collection updates but are not integrated into algorithm changes.

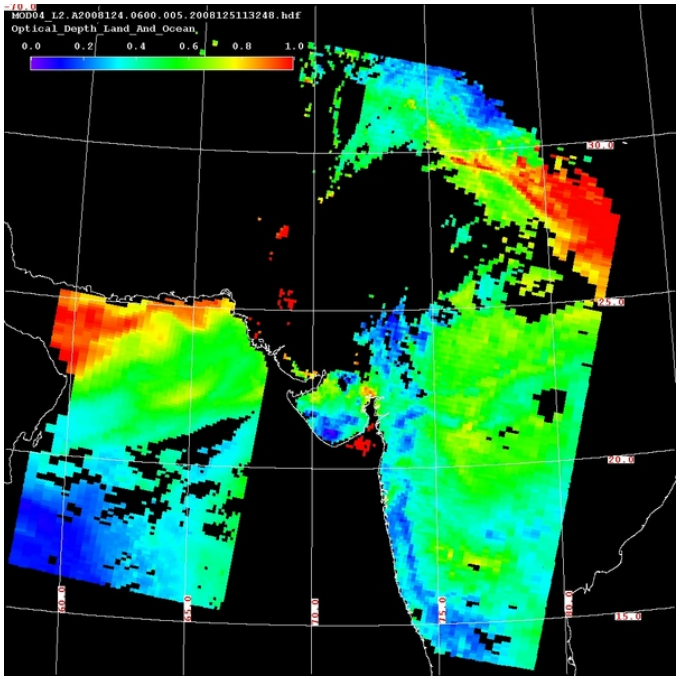
Level 3 – Covering the Globe

1 degree resolution, so products are averaged from their native retrieval resolution.

Averaging is either straightforward or weighted by a quality flag.

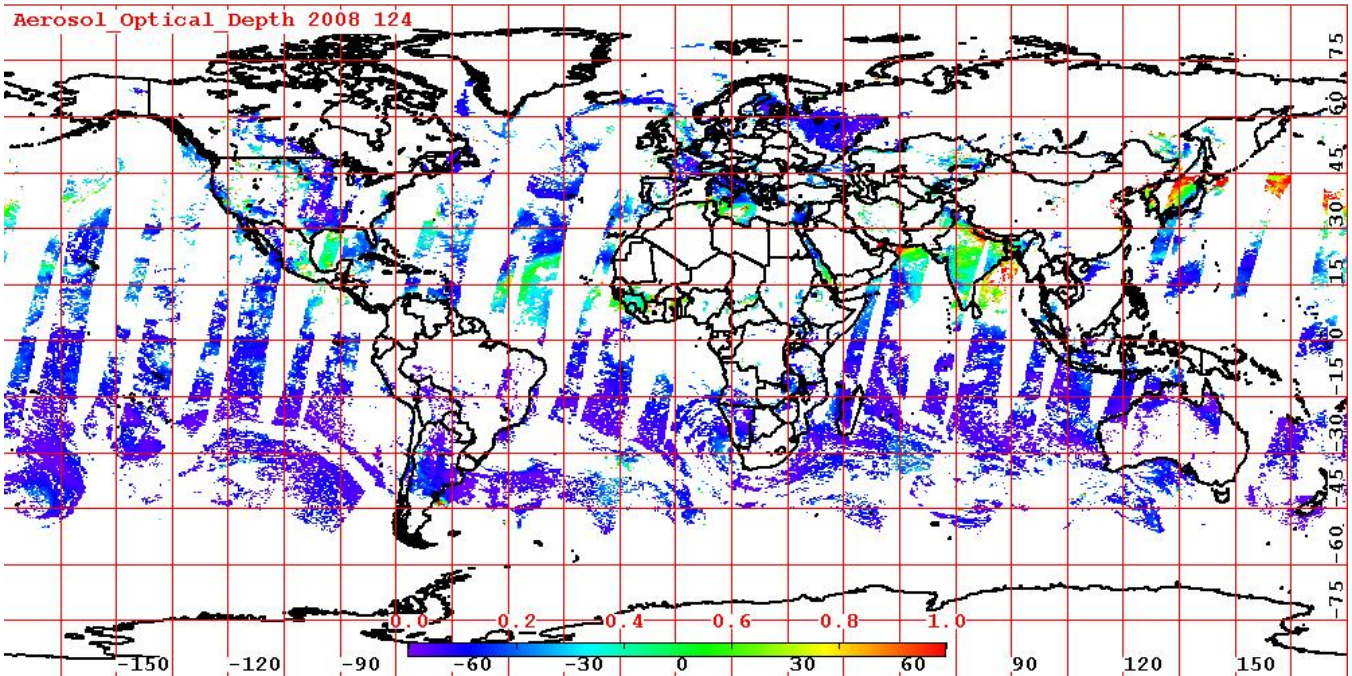
Daily
8-Day
Monthly averages available.

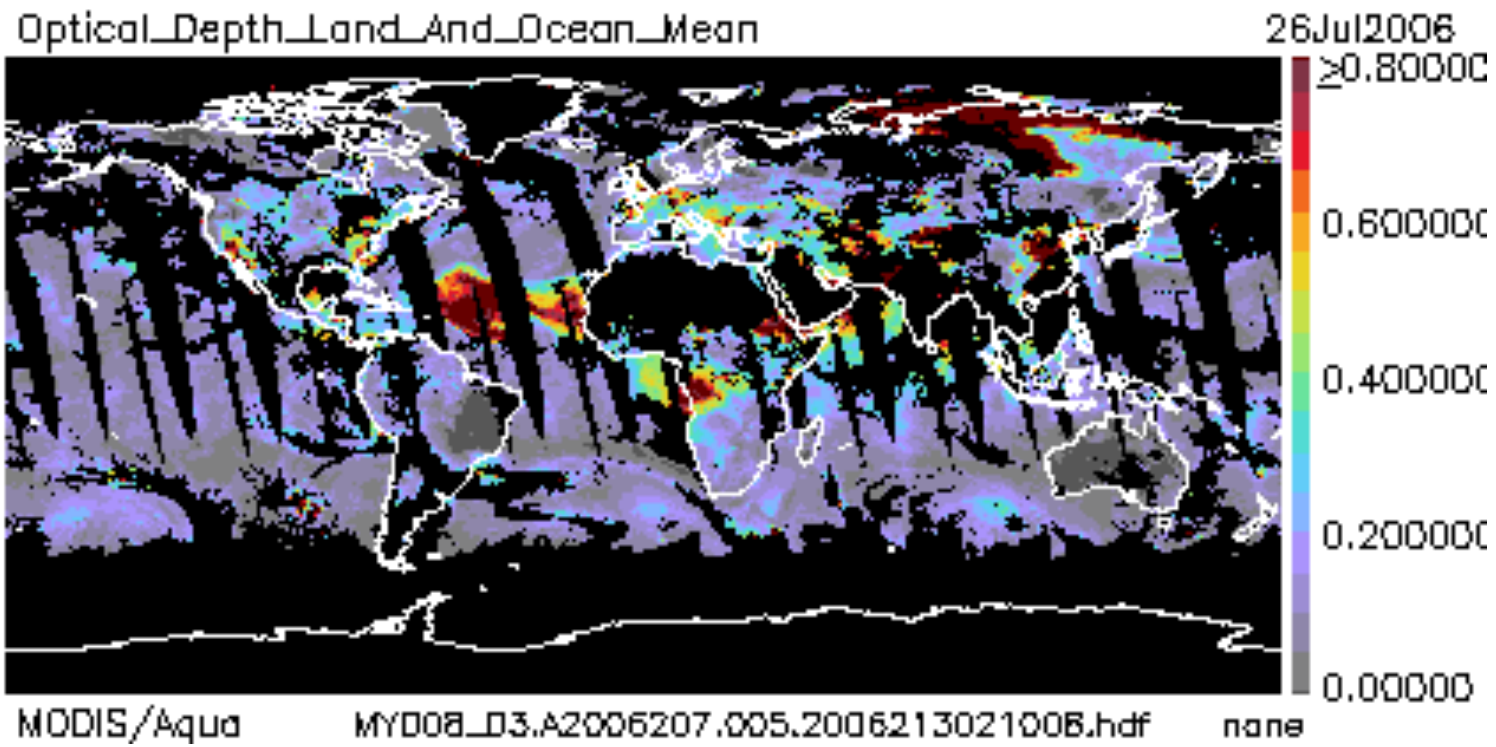
Note that one grid square can contain multiple orbits.
Level 3 is not synchronous in time!



Level 2 Aerosol Product (AOD)

Level 3 Aerosol Product (AOD)



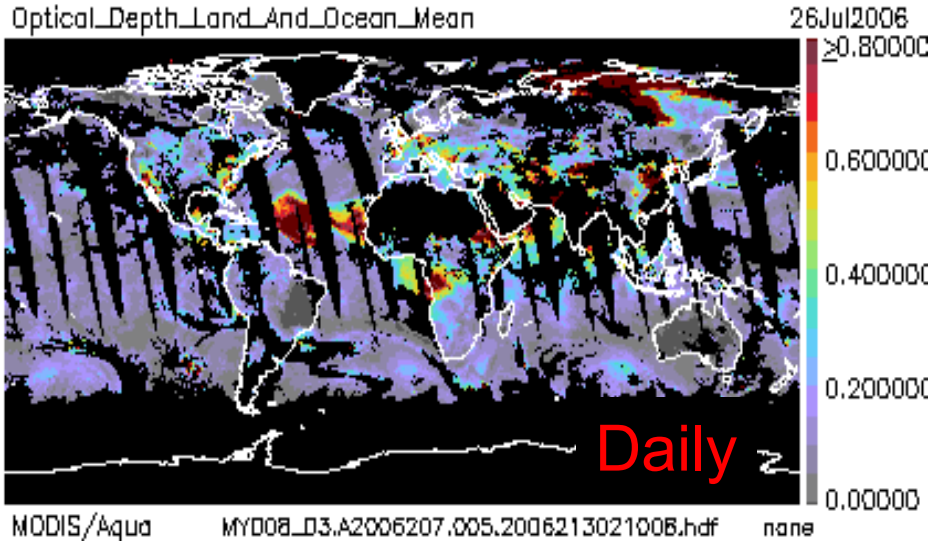


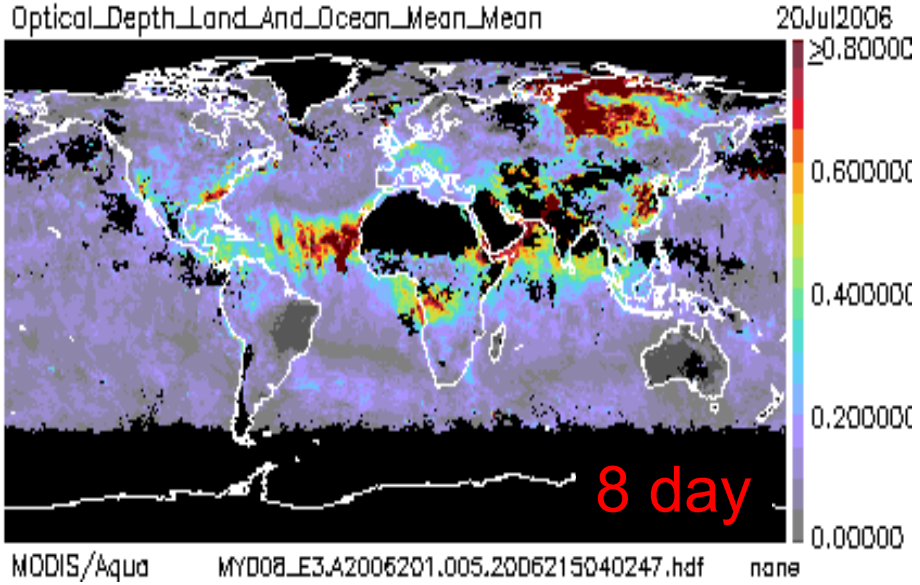
Daily L3 aerosol optical thickness over land and ocean

The large gaps over ocean are due to Sunglint

The gaps over land are due to bright surfaces and gaps due to cloud systems.

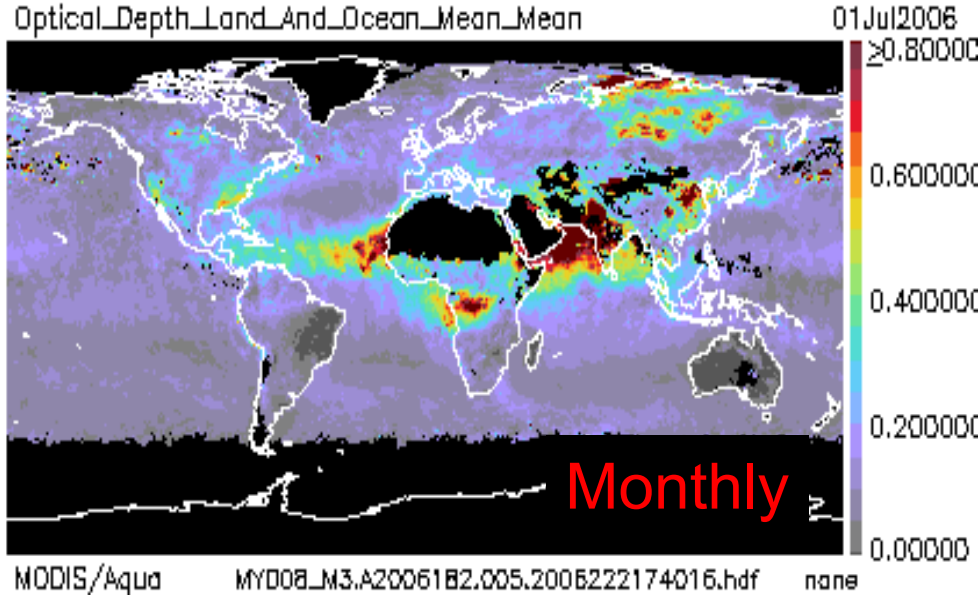
Regularly spaced gaps near the equator are due to lack of coverage between orbits.





Daily = MOD08_D3
8-day = MOD08_E3
Monthly =MOD08_M3

Less missing data
with increasing time interval!



Level 3

Also comes with an array of statistics:

Means, standard deviations, max and min retrieval in each grid box.

Histograms and joint histograms between products.

Number of pixels that went into the mean of each grid box

Caution: Many things change from sensor to sensor or even within one sensor product over time!

Calibration accuracy.

Quality Assurance – product creators' estimate of the quality of the data.

Data formats.

Product Resolutions.

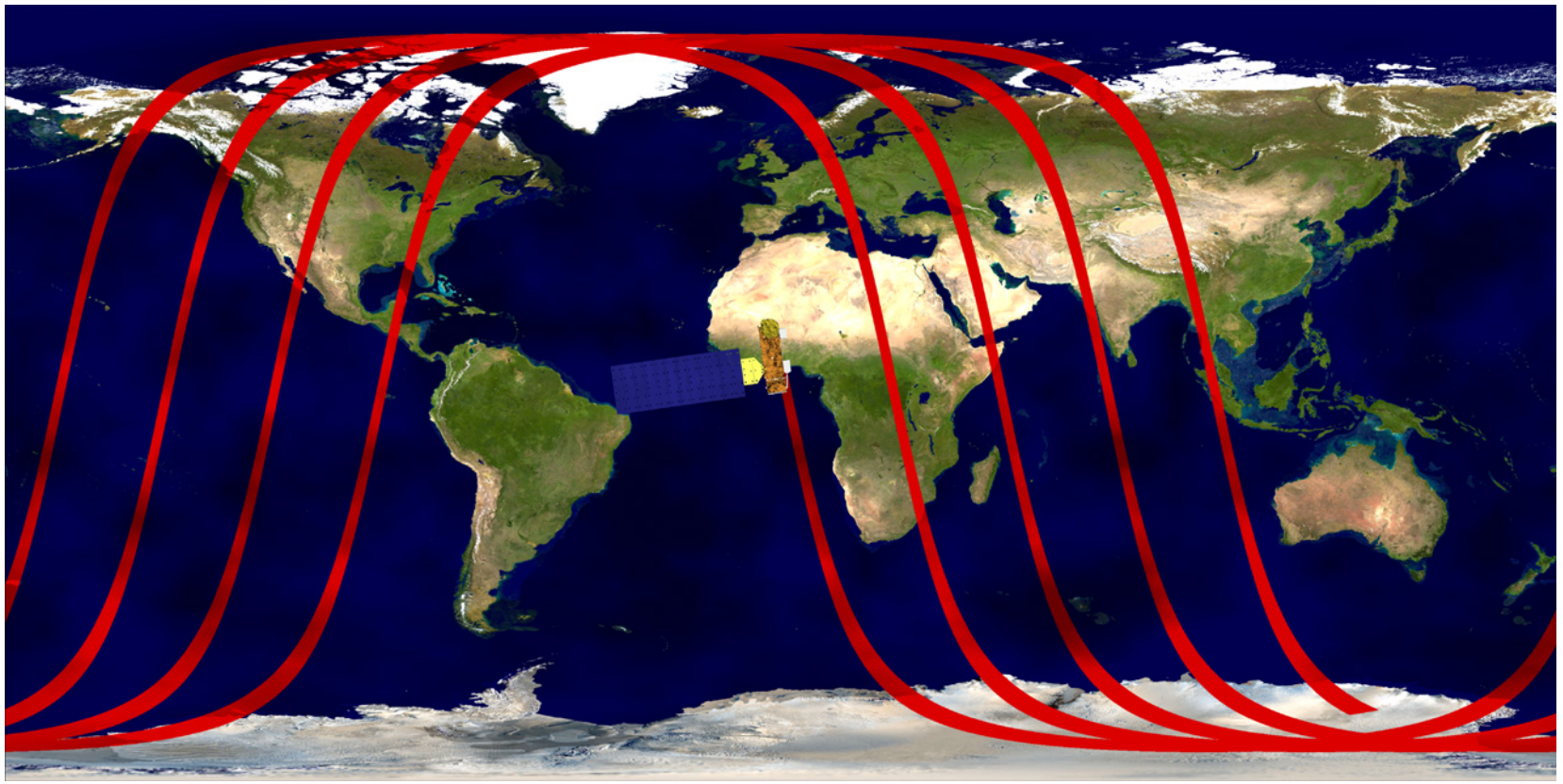
How level 3 products are created from level 2, temporally and spatially.

Current release of the data and data history.

Part Two

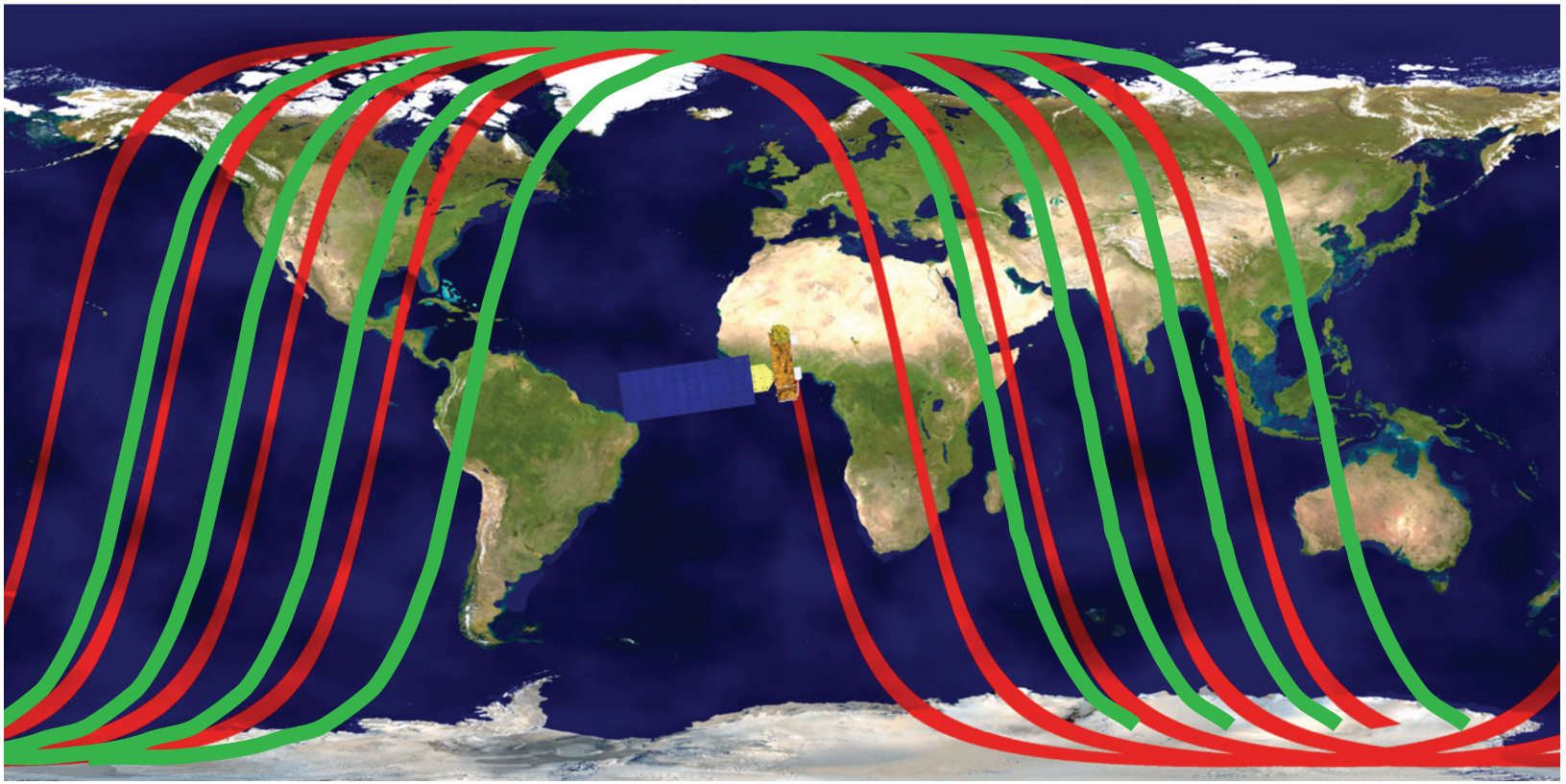
Aqua's Orbit

- **Daytime Ascending at ~ 1:30 p.m. local time**
- **Near – Polar, Sun Synchronous Orbit**
- **Approximately 15 orbits per day**

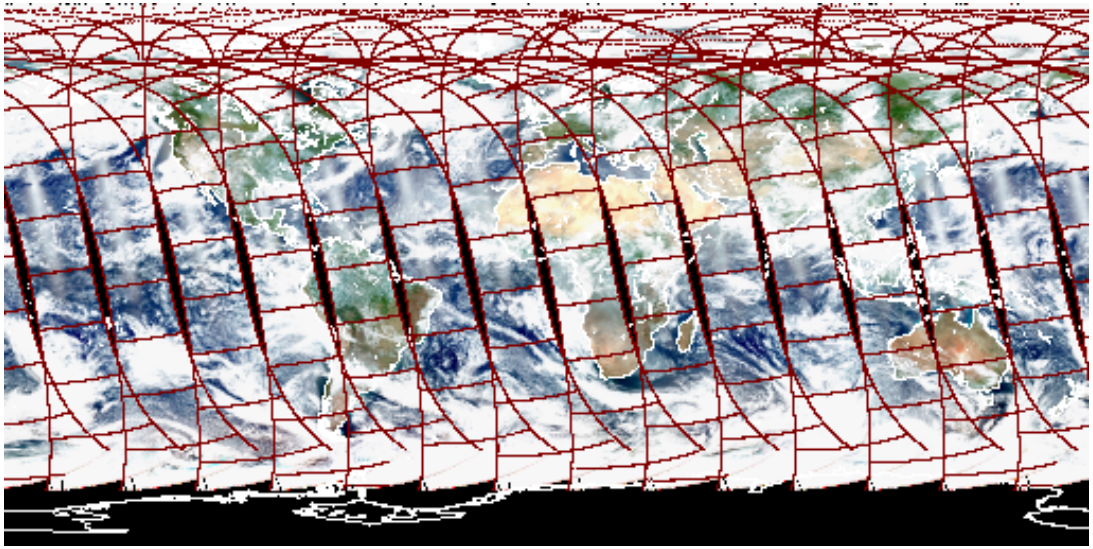


Aqua's Orbit

- **Orbital track changes every day.**
- **16 day repeating cycle**
- **This is true for both Aqua and Terra.**

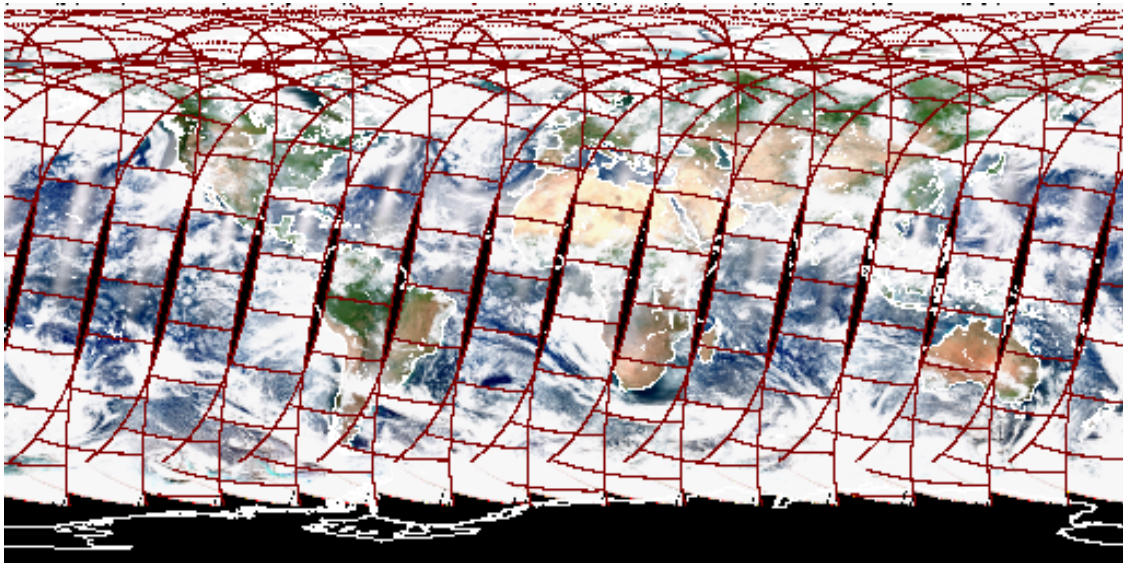


MODIS-Aqua (“ascending” orbit)



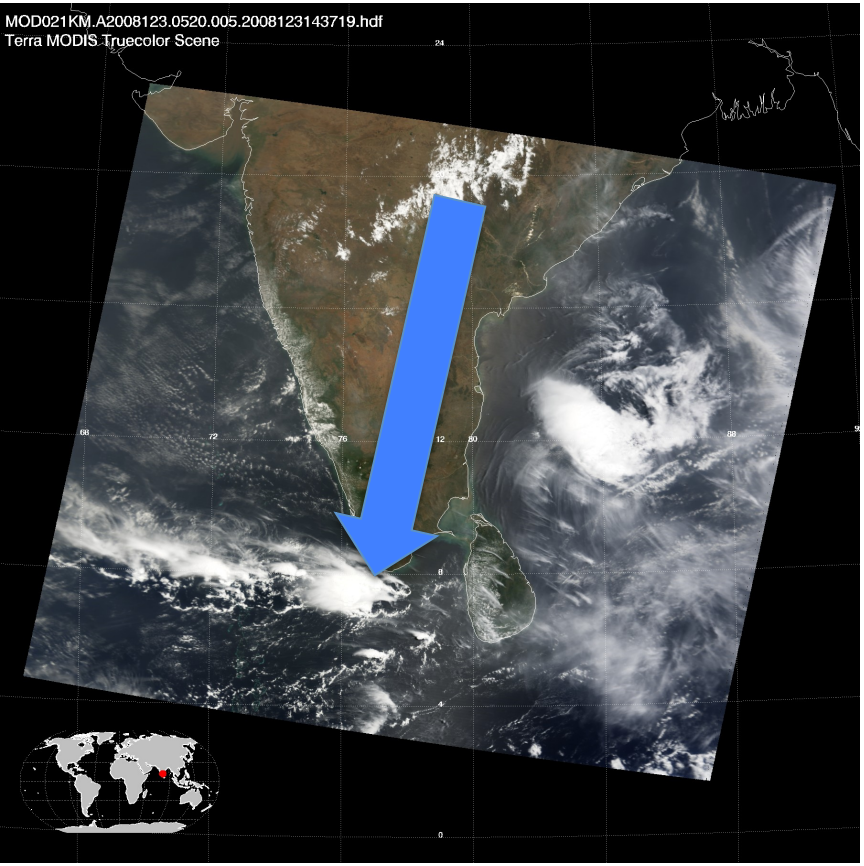
Red outlined squares depict granule locations within the orbital swath

MODIS-Terra (“descending”)

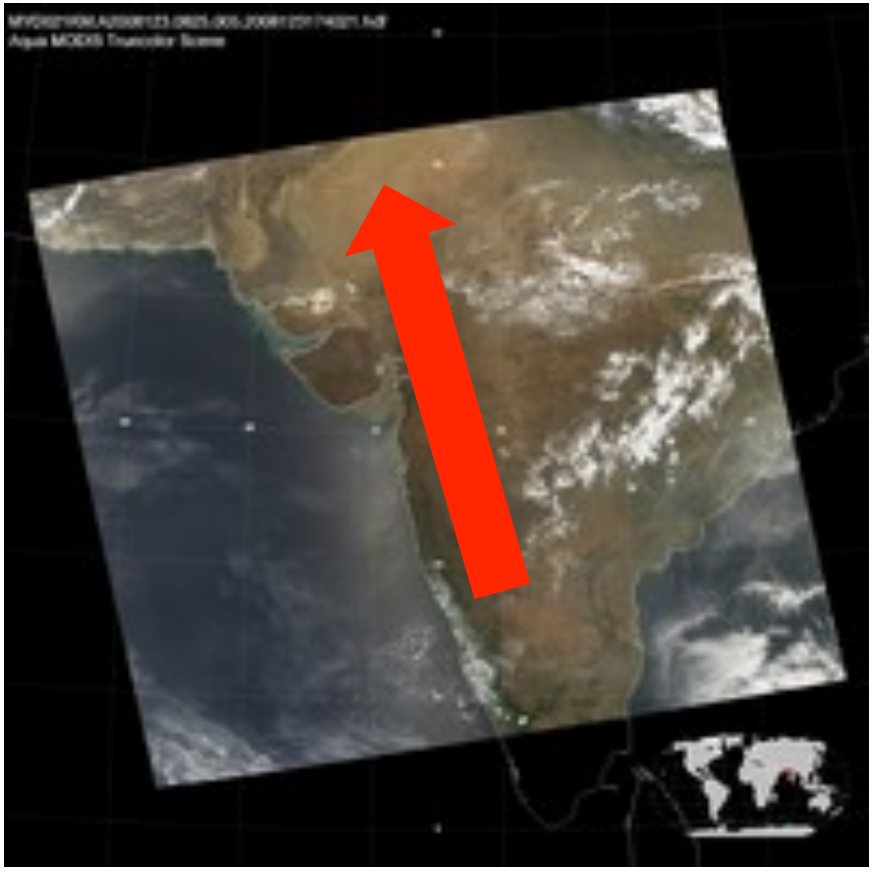


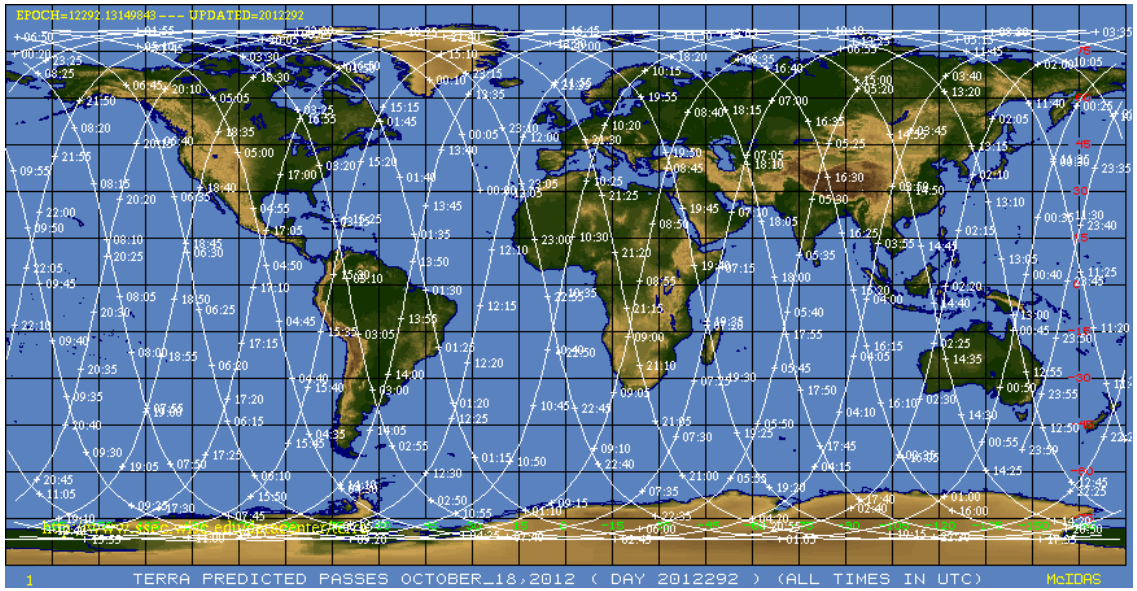
MODIS – NASA's Primary Sensor for Earth Science Observations

Terra ~ 10:30 Morning
Daytime Overpass
Descending Orbit

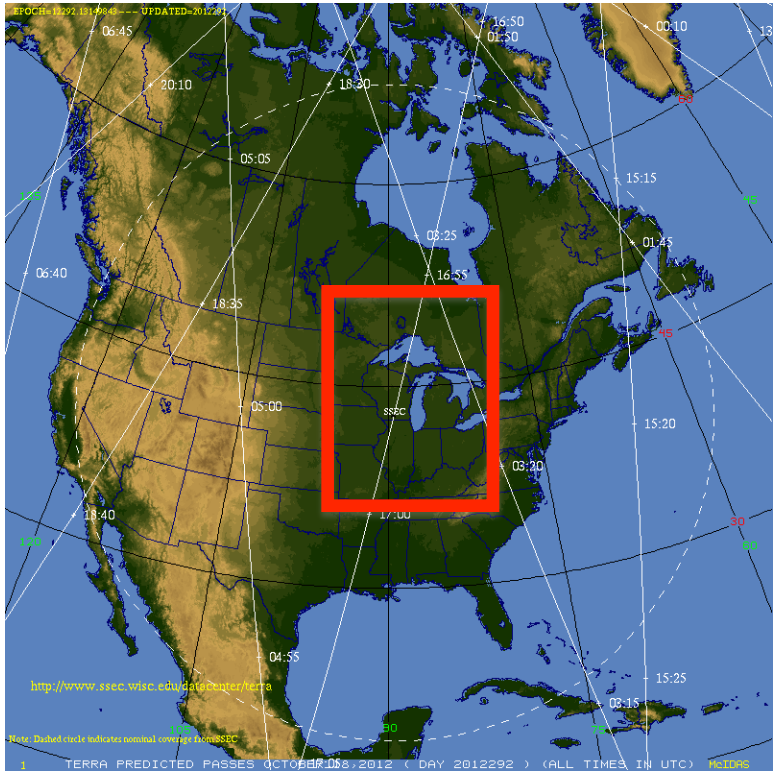


Aqua ~ 1:30 Afternoon
Daytime Overpass
Ascending Orbit





Overpass Maps for Terra



Approximate Area Covered for granule labeled “16:55”

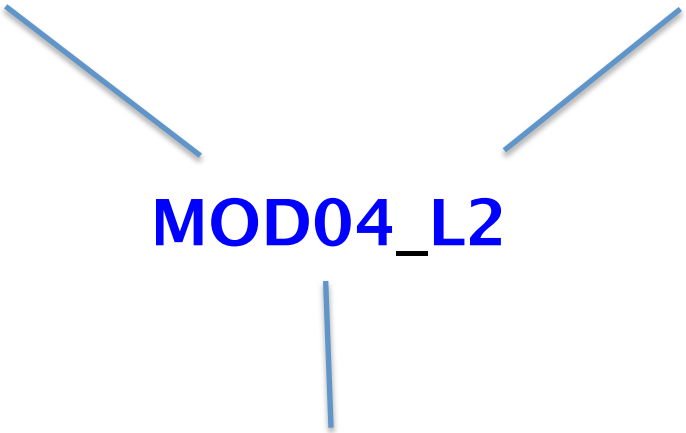
Understanding a MODIS File Name

Sensor Designation

MOD = Terra
MYD = Aqua

Product Level

1,2 or 3
More on this later



MOD04_L2

Product Type

04 = Aerosols
06 = Clouds

Understanding a MODIS File Name